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Simultaneous Drill and Case Technology - Case Histories, Status and Options for Further Development

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Abstract

Drilling liner technology has become a standard for entering depleted reservoirs in areas of the North Sea and Southeast Asia and interest continues to increase for use of drilling liners to overcome other drilling problems. Marketing analyses have shown that further development of drilling liner technology and application has been rated with high priority.

Based on experience gathered during the last five years, this paper covers possible further Drilling Liner applications, new challenges, and requirements for new systems. "Drill and Case" systems will be introduced and benefits shown by means of case histories of jobs carried out in Norway and Indonesia.

Introduction

Drilling Liner technology seeks to drill and case the well in one run. Over the last five years, typical Drilling Liner runs were carried out in applications where the target depth was just a few meters away, but could not safely be reached with standard drilling bottom hole assemblies (BHA's). Drilling ahead with standard BHA's risked loss circulation, hole collapse and potentially losing the BHA, drill string and hole section. The success of the entire well was dependent on drilling just a few meters ahead.

Drilling Liner technology has helped solve these problems in Norway and Indonesia — enabling savings of over 1.0 mm US$ per well.

A typical Drilling Liner application occurs when drilling into depleted reservoirs — a situation, which will become more evident and critical in the future. Former drilling technology has required the use of intermediate casing strings and/or set cement plugs as a means to achieve this. Using Drilling Liners, it often takes only a few hours to drill the liner to target depth and overcome existing drilling problems.

The Drilling Liner was standardized to enter depleted reservoirs, but questions challenging the use of this system in other applications continue to arise. These new applications include long distance (ERD) drilling, deep water/shallow water flows, unconsolidated sands or time critical unstable formations.

Market analysis has shown that further development of "Case and Drill" systems are rated within the top level of desired drilling technologies industry-wide. On the other hand, although existing systems have been on the market for some years, they are sometimes not fully recognized as potential cost savers or problem solvers.

Case and Drill Simultaneously.

Various liner drilling systems and casing drilling systems are on the market. *Figure 1* refers to liner and casing drilling concepts. Using casing drill systems, the operator can change the drilling BHA several times, whilst the casing stays in the hole. Due to the fact that the casing reaches to surface, the BHA can be retrieved with jointed pipe or wireline. Under-reamers or extendible bits enlarge the hole to allow the casing to follow. The casing must be designed to withstand all drilling loads from the bottom of the well up to surface.

Liner drilling systems allow just enough casing to case the open hole and omits the upper part of the casing string. The drill pipe string therefore carries the main drilling loads, especially when drilling in rotary mode. A liner hanger is used to connect the surface string with the liner and run the BHA to target depth. Because of this, the drilling BHA can be retrieved only when the hole is finished. Currently liner hanger systems are not able to release and connect the liner downhole several times to trip the drilling BHA into and out of the hole. In case of a BHA failure, it is required to pull the entire surface and liner string for an intermediate trip. It is therefore of major importance, that a drilling liner BHA is reliable for the entire required hole section eliminating the need for tripping. Equipment drilling life and optimum liner hanger positioning within the upper casing string, limit the maximum drilling length.

There are both pros and cons for general case and drill technology. Small annular spacing leads to higher ECD's and increased bottom hole pressures and high flow rates might not be possible. Also, bit cooling could be adversely effected. Higher mud velocities in the annulus might improve cutting transportation, but small annular clearances between the packer and casing could lead to sedimentation of cuttings in the liner hanger / packer area. In addition, kick control may be more difficult, since the kick comes to surface faster. Special kick detection systems (KDS) similar to those used for slim hole drilling could be required.

If the liner / casing must be rotated, abrasive wear and reduction in burst and collapse pressure should be considered. Smaller motors are used to drill the well, because the liner or casing drift - not the well diameter - must allow for retrieval of the BHA. As an example, 4 ¾" motors instead of 6 ¾" motors are used to drill 8 ½" hole sections. In soft or shallow formations the rate of penetration (ROP) might still be acceptable, but in deeper or harder formations the smaller motor and reduced power could be insufficient and lead to a decrease in ROP, or motor overloading, with liner/casing drilling. *Graph 1* compares the power of 4 ¾" and 6 ¾" motor sections. Looking back, it can also be seen, that today's 4 ¾" motors exceed the power of older 6 ¾" motors.

The risk of getting differentially stuck or mechanically stuck is increased when drilling with liner/casing instead of standard drilling BHA's.

All of the above topics should be considered when running a drill and case BHA. Drill and case technology will therefore not replace standard drilling, but could enable breakthroughs in several complicated drilling applications.

Maximum Drilling Distances with Drilling Liner Systems:
The maximum distance to be drilled with a liner is an important factor with this type of system. The main difference between casing drilling systems (casing reaches to surface) and liner drilling systems (liner is run below a liner hanger with drill pipe to surface) is the inability to trip the liner drilling BHA through the liner hanger to allow several trips in one run *(Figure 1)*. The operational life of the drilling liner BHA must therefore exceed, or at least cover, the entire required drilling distance with an acceptable safety margin to mitigate risk.

In general, the drilling distance will be limited by the optimum position of the packer in the upper casing and the maximum lifetime of equipment used with the drilling liner.

Also, rotary driven liner systems will be limited by torque limitations, bit and liner wear. Both should be calculated or estimated prior to the run. Motor driven liner systems (slide drilling or combination of slide and rotary drilling) will be limited by the lifetime of the motor and bits. Offset data from former wells (motor/bit lifetime and ROP) will help to estimate the maximum drilling distance. Both factors are dependent on formation, application, location, facilities and auxiliaries. Mud cleaning systems should be optimized to avoid abrasive wear of the motor section. When drilling with a liner, the goal should be to drill to target depth in one run and not to reach high penetration rates. A downhole tool failure leads to lost time in tripping and possible other problems like hole stability. By multiplying *Offset Rate of Penetration x Offset Lifetime (PDC bit, motor)*, drillers can estimate maximum drilling distance. The optimum placement of the packer (liner stand off inside the casing) should be considered accordingly.

Drilling Liner Application

Drilling Liners have been used in the past in accordance with the following operational steps. Drill with standard BHA's as far as possible (due to larger available motor sizes, more easily to handle ECD, liner equipment protection, etc.). Retrieve standard BHA and drill ahead with the drilling liner BHA to target depth.

To drill with a liner can help to overcome several well problems. For one of these problems (drilling into highly depleted reservoirs), the current technology is already tested and proven reliable. However, other applications would require an immense engineering effort to design a liner drilling system able to overcome the operational challenges presented.

Drilling into Adjacent Formations with High Differential Pore Pressures *(Figure 2):*
A typical case is the entry of depleted reservoirs, which are overlain by a higher pressured overburden formation. When entering the reservoir with a standard drilling BHA, severe mud losses occur and the mud column height drops to equalize the reservoir pressure. Due to the lower mud level in the annulus the well loses its balance to the higher pressure of the upper formation. Potential results include kicks, hole collapse of the upper formation and stuck pipe. Quite often the BHA cannot be retrieved and the open hole section is lost. The current (and most prevalent) practice is to set intermediate liner strings to minimize and/or eliminate the problem. However, as a consequence, operators will have to work with smaller tool sizes in the reservoir.

Drilling Liner technology avoids an intermediate liner. The entire liner is set simultaneously while drilling into the depleted reservoir. The liner is already in place as soon as problems occur. Drilling liners have proven to be reliable and have been standardized for this kind of application (see Mobil Arun field and Amoco Valhall field).

Drilling Unstable Formations *(Figure 3)*:
When drilling time dependent unstable formations (i.e. salt, shale, etc.), the maximum section length is often limited by the incoming formation. To ensure sufficient well diameter to run a subsequent liner string, the borehole is usually under-reamed to a larger hole size. Another option is to drill and cement several short intervals. The cement will have to be drilled out each time before drilling the next formation interval. Both of these procedures are time consuming and cost intensive.

Another option is the use of an expandable liner. This permits the operator to drill ahead without a telescopic reduction in the wellbore size.

Alternatively to drill directly with the liner can save potential trip time. Also, surge and swab pressures whilst tripping standard drilling BHA's in and out of the well can be avoided.

Today's available drilling liner technology could be considered to drill these wells. However, careful consideration must be given to the drilling distance being planned for the run.

Drilling Deviated Wells Through Unstable Hole Sections, Unconsolidated Sands or Elongate Well Sections *(Figure 3)*:

The problem is similar as discussed before, but the main focus is set on steering and directional control when drilling with the liner. To follow a proposed well path steering will be required, especially in long hole sections. Blind drilling, from a directional perspective, might be possible in some applications. However, if well deviation is required, current drilling liner technology is limited. Proposals for steerable drilling liner BHA's have been designed but never built. The simplest design extends the BHA out of the bottom of the liner with a bent housing drilling motor, MWD and under-reamer. The motor drills the curve and the liner follows the under-reamed hole. To enable getting the liner to the bottom of the well, a more elegant solution is to include a retrievable tool with e.g. steering pads direct into or below the bottom of the liner.

If no contingency option is required, a disposable motor on the liner bottom is a possible solution for setting the production liner deeper into the reservoir.

Deep Water Shallow Water Flows *(Figure 4)*:

In deepwater applications, the first hole sections are often drilled without a marine riser with returns to the seabed. After the hole for the conductor pile and/or casing is drilled, the casing is cemented in place and the BOP stack is connected to the wellhead. The riser is then connected to the BOP stack.

In the Gulf of Mexico, shallow water flows from sand layers occur in hole sections prior to setting the casing or wellhead. Shallow water flows are leading to conductor / casing erosion and formation wash outs along side the casing. Setting the wellhead or BOP stack can then become impossible and quite often the well must be abandoned.

The use of drilling liner technology, including an immediate casing/cementing option, could help stop shallow water flows in time, but several other technology steps and solutions are required to overcome problems associated with this technology. A casing/wellhead system capable of being drilled with must be developed. Furthermore, contingency plans for excess length of casing are required, if the problem occurs prior to getting to the planned depth. Liner hanger or landing systems for 20" casings and larger must be developed. Intermediate cementing options, eliminating the risk of cementing the drilling BHA (motor) in place, will require specially designed valves included in the BHA.

Beds with Fractures at Unknown Depths *(Figure 5)*.

Even when maintaining the mud conditions across the reservoir, standard drilling equipment will get stuck when drilling from one fracture into an adjacent one. Immediate downhole blowouts will lead to formation collapse, drop of the mud level and/or kicks from upper formations. To subsequently run liner in the hole is not possible.

However, using drilling liner technology, the liner would already be in place when hitting a new fracture.

The problematic issue will be the unknown depth of the fractures and therefore the unknown length of the required drilling liner or the drilling distance. Furthermore, an immediate cementing option is required to avoid similar erosion problems similar to those discussed in regard to shallow water flows. To drill these wells with a combination of expandable liner and drilling liner could be the optimum solution.

Saving of Rig Flat Time:

Another question is whether rig time can be saved by fully replacing standard drilling BHA's with liner or casing drilling. Defining the system's pros and cons is of major importance. It might be correct to argue that trip time can be saved when drilling with a liner instead of running the liner in hole on a subsequent run. However, when comparing both procedures, some cons of the currently available drill and case systems become obvious.

The small annular clearance between the hole size and the outer diameter of the liner leads to a higher risk of differential sticking and mechanical sticking problems. As long as the string can be freed with a safe reduction of the mud weight (or by pumping a pill) the risk may be acceptable. However, if jarring is required, the problem could become severe. Jarring might not be possible in casing drill systems and would be very limited in liner drill systems. All overpull forces must be transmitted through the liner connections. If only the inner drilling BHA gets stuck in the hole (extended inner string system), standard drill pipe must be on location for jarring and fishing purpose.

Another drawback would be a reduced drilling ROP due to smaller available motor sizes for the reduced hole size. In shallow or soft drilling applications this could be of minor consequence. However, in hard rock applications, the overall gross ROP could be reduced significantly compared to drilling with a conventional BHA and drill pipe.

Downhole tool failures with a drilling liner BHA require tripping the entire liner out of the hole. Along with normal tripping risks (stuck pipe, swabbing, etc.), there is also the risk associated with the liner connections which do not have the robustness of drill pipe connections.

In the case of rotary applications, liner wear will reduce burst/collapse resistance. The condition of the liner after it is used for long rotary drilled hole sections is unknown.

Pack-offs are more likely to occur with the tight annular clearances, and cuttings settling may cause stuck pipe when circulation and string movement is interrupted for connections.

Also, adequate steering, measuring and logging-while-drilling services are not currently available (or feature reduced options).

All of the above mentioned issues must be considered when weighing the pros and cons for reducing rig time.

At the present development stage, liner drilling technology cannot replace standard drilling technology and savings in rig time are doubtful.

Drilling Liner Systems

There are several currently-available drilling liner systems which have been used successfully in the field. One is a rotary driven system with a special drill bit on bottom as described by Alan Sinor[1] *(Figure 6)*. The second is a motor driven system with a swivel and crown/core bit at the bottom of the liner. *(Figures 6,7,8)*. The third system used is the motor driven Amoco/Wenande system without swivel, but with under-reamer below the liner *(Figure 6)*.

All three systems drill with the liner and ensure that the liner is in place in case of hole collapse problems. A fourth option would be to use a disposable motor below the liner and leave it in the hole after the drilling operation is finished. This option was discussed with regard to running a 5 ½" production liner and extending the well within the reservoir.

The First System, a Rotary Driven System includes a standard liner, which is connected at the top to a liner hanger and features a special design PDC bit on bottom. The main feature of the bit is that it can easily be milled out from the inside on a subsequent clean out run, after the liner has been set. Drilling parameters, rotary speed and torque are delivered from surface via the top drive or the rotary table. This system is essentially a conventional drilling system with the drilling liner itself being part of the drill string and the bit essentially being a regular drill bit. This system's limitations lie primarily in the need to be able to rotate the entire string. As a result, the applications for this method lie primarily with low inclination wells and/or short drilling liner applications.

The Second System *(Figures 6,7,8)* named BHI system was described by C.Vogt[2] and features two drill bits. A crown/core bit and a pilot bit. The crown/core bit belongs to the liner and is located below a swivel assembly at the bottom of the liner. The pilot bit belongs to the retrievable inner string. A downhole motor drives both bits at the same torque and speed. The drilling liner drills in sliding mode but can also be rotated from surface as well, if torque capacity and torque limits allow.

The motor is placed inside the liner and is either connected to the liner hanger via standard drill pipe or connected at the bottom of the liner with an additional releasing tool. The second option omits the long inner string and could save considerable rig time while running the liner.

The standard drilling liner uses the full inner string with a special BHA including a thruster, motor and pilot bit. After the liner is set, the inner string is tripped out of the hole. The remaining outer string is part of the casing string and has full drift allowing an immediate option of contingency.

The Third System named Amoco/Wenande System *(Figure 6)* consists likewise out of two strings (liner and inner string) which are connected either on top to the liner hanger or at the bottom via a second releasing tool (to omit full inner string length). However, instead of a swivel and a crown bit on bottom, the outer string consists just out of a standard liner (without bit). The bottom of the liner is tapered to decrease the risk of slip stick effects. The inner string features a downhole motor with an under-reamer with pilot bit on bottom. The under-reamer extends out of the outer string and is used to enlarge the hole size to enable the liner to follow. A bullnose or pilot bit is connected below the under-reamer. The pilot bit would be used to drill a pilot hole for full drilling purpose. The bullnose option has been used to follow a pre-drilled hole to eliminate the risk of sidetracking. After the liner is set, the inner string is retrieved.

A Disposable Motor System could be used, if no contingency option is required (e.g. production liner) and the lost in hole costs for the motor are justified. In this case, the motor would be screwed via a cross over to the bottom of the liner and can be used to either ease running the liner in the hole or to elongate the setting depth of the liner.

Drilling Liner Considerations:

Ideally, drilling liners should allow full drift diameter access over the entire liner length after the application is finished. To save rig time, milling operations should not be required (or should be of a minor consequence). This criterion is fulfilled by all the Drilling Liner systems discussed above.

The availability of liner hanger and releasing tools for certain liner drifts must be clarified prior to a drilling liner application.

Another criterion is the inner string of the BHA. The weight of the inner string increases the hook load and the friction of the liner in highly deviated wells. Torque and drag analyses should be carried out to estimate the maximum setting depth when using a complete inner string from pilot bit to liner hanger.

If using the system without an inner string, the drilling BHA is retrieved out of the hole on a separate trip (after the liner hanger is set). As long as jointed pipe is used to retrieve the BHA, gross trip-time-savings might be negligible. However, the advantage is evident in unstable hole sections. The fishing procedure takes place when the liner is already at its final position and the borehole is protected. In case of unstable hole conditions, time savings to avoid tripping the inner string might be considerable.

To run the liner without an inner string features other advantages. In this case, hook load, as well as torque and drag, will be reduced.

The thruster as part of the inner string is not required. It usually serves to compensate possible length differences between the inner and outer string. Without using the inner string, hydraulics regarding the thruster can be ignored.

However, kick control can be complicated due to not having an internal string on bottom. On the other side, a triple water bushing for kick control purposes when tripping the inner string in hole is not required.

The "without inner string" system can be used without any additional equipment on standard rigs capable of running liner / casing strings.. The BHA is fully pre-assembled in the local workshop and delivered as a complete sub to be made up below a standard liner and no changes at the rig site are required. Open hole trip time can be reduced.

The casing above the liner should be investigated for the optimum packer and hanger position. Contingencies should consider that the liner could get stuck above or below the desired or optimum position.

In the case of a very short drilling length (<90 ft), a rig with a top drive should be used (instead of kelly drive) to avoid pulling the liner off bottom when making connections.

Case Histories

Drilling liners have only been used in a very small spectrum of the prior mentioned possible applications. Primarily, BP Amoco in Norway and Mobil in Indonesia are using drilling liners to re-enter depleted reservoirs *(Figure 9, Table 1)*.

The Mobil Arun field is located in North Sumatra / Indonesia. The top of the depleted gas reservoir is approximately at 2900 - 3200 m TVD. The equivalent formation pressure of the gas carrying pay zone has been reduced, due to production, to 2.5 ppg EMW. The overlaying shale formation has a 16.8 ppg EMW formation pressure, 14.3 ppg EMW larger than the reservoir's pressure. Problems, which occur when drilling into the highly depleted reservoir with standard drilling BHA's, have been described under "Drilling into Adjacent Formations with High Differential Pore Pressure". The Baker Hughes drilling liner was developed in 1995 to specially overcome these problems(2). Three successful runs had been carried out at this time, but the project was abandoned, due to unsolved problems related to being able to easily release and retrieve the inner string. Also, the available 4 ¾" motor power was insufficient to drill the 8 ½" hole sections.

The project was revived in the summer of 1997, when MEPTEC (Mobil Exploration and Producing Technical Center) and Baker Oil Tools became involved to deliver a reliable releasing tool and make the whole system an overall success. Using a new motor section, the available power was increased (240% compared to the old 4 ¾" power sections and 16% greater than the old 6 ¾" power section). Meanwhile, 4 ¾" motor sections can be made available featuring 83% more power than old 6 ¾" power sections.

Since then, six further successful 7", 35 lb/ft drilling liner runs have been carried out in 1997 and 1998. These runs were accomplished without any problems drilling the BHA to target depth nor releasing and pulling the inner string. Existing wells were sidetracked with standard BHA's out of section-milled casings or whipstock opened windows. Before entering the trouble zone, the standard BHA's were retrieved and the remaining section drilled with drilling liner BHA's to target depth. Target depth was defined as "drill ahead as far as possible until the equipment gets stuck within the pay zone". Usually 50 rpm rotary speed from surface was applied, but was increased up to 100 rpm on Arun C-IV-ST. When entering the pay zone, the rotary torque increased to the operational limits due to the incoming shale formation. Changing the parameters to pure slide drilling with increased WOB enabled the operator to further extend the liner setting depth into the pay zone. In November 1998, this drilling practice was optimized and the liner setting depth was finally limited by the optimum packer position inside the casing and not by getting stuck with the liner. The liner connections were changed from TC4S with collar to IG4S without collar. The IG4S connection features a flush joint what possible eased sliding ahead. The drilling ROP could be increased from 4 ft/hr to 12-14 ft/hr. A record was also established by setting the liner 61-ft into the reservoir. This depth does not sound too far, but must be seen in relation to the pressure difference between the overburden shale and the reservoir pay zone of 14.3 ppg equivalent mud weight. On former applications the drilling liner got stuck immediately after the reservoir was entered — with the shoe only a few feet into the reservoir.

The liner hanger used was the SDD (Solid Drill Down) liner hanger. This kind of liner hanger is an integral manufactured version and able to withstand rotary drilling loads. The outer diameter features tungsten carbide gage protection to avoid abrasive wear of the liner hanger whilst rotating. Bypass channels for the mud flow around the hanger have been increased to reduce the annulus differential pressure. The integral releasing tool can be activated either hydraulically (while dropping a ball) or mechanically (while applying pre-adjusted left hand torque). The "two choice" release mechanism ensures easy retrieval of the inner string. The duration of the entire procedure to release the inner string takes only a few minutes.

On the first three wells, the liner was subsequently perforated and attempts were made to squeeze cement between the liner and the hole. However, this was unsuccessful and it appeared that the collapsed shale formation around the liner had sufficient sealing capability and cementing was not required on further runs. A listing of case histories is shown in Table 1.

In the meantime, Baker Hughes drilling liner technology has been standardized for Mobil in the Arun field.

BP Amoco in Norway uses different drilling liner technologies to enter the depleted areas of the Valhall field. In addition to the BHI drilling liner system, the Amoco/Sinor drilling liner bit and the Amoco/Wenande drilling liner system have been used.

The Valhall field is located offshore in the North Sea. The sea floor is approximately 72 m below sea level. The oil-carrying, depleted Tor formation has an equivalent formation pressure of less than 7.0 ppg equivalent mud weight (EMW) in the crestal area and is covered by the 14.7 ppg EMW Lista overburden formation. The reservoir top is at approximately 2400-2500 meter TVD.

Amoco had already started in 1993 with drilling liner options and carried out their first of several successful runs in a row (from 1995 to 1998) with the HC/Sinor drilling liner option. The Amoco/Wenande system was also used on two occasions (1994 & 1998), but with different approaches. The original application (1994) was to drill the overburden section to achieve the depleted reservoir on a Hod well. This application utilized an internal string within the 9-5/8" casing and had an under-reamer and bit protruding below the casing guide shoe. The inner string was positioned inside the 9-5/8" casing by means of a casing spear. This system was successful in drilling over 75 feet of hole before becoming stuck immediately above the reservoir. The application was successful and contributed to major cost savings for the well. The purpose during the latter (1998) application was to bring the liner down to TD of a pre-drilled hole on the Valhall A-3C well and not to drill ahead with the liner. In the 1998 application the bullnose was used instead of a pilot bit to centralize the BHA in the pre-drilled hole section. In the 1998 application an under-reamer and the bullnose were again placed below the 9-5/8" casing guide shoe but there was no internal string used. The under-reaming BHA was pinned and sealed onto a specialized casing joint which eliminated the need for an inner string. The liner was run but saw only limited success as the liner did not reach bottom. However, the internal BHA was successfully retrieved and the concept was proven.

In November 1997, Amoco used the BHI system successfully for the first time. The application resulted from the unavailability of required surface torque to drill the Amoco/Sinor drilling liner in rotary mode to the desired TD. The new 9 5/8" tool size was designed for Amoco and also used the first time.

The BHI drilling liner used on the 2/8-F 17 well, with a length of 2100 meters, was the longest ever used for a drilling liner application at the time. After 19 meter of pure slide drilling, the liner was successfully set into the top of the reservoir. The liner was subsequently cemented in place using Halliburton's FO cementing tool, a first time use in combination with the drilling liner, which since has become a standard part of drilling liner applications at Valhall. In this application, the varying reservoir pressure along the horizontal hole forced the setting of a 7 5/8" contingency liner after drilling <300m inside the pay. The availability of the contingency was only due to the successful drilling of the 9 5/8" liner into the top of the chalk formation. This allowed Amoco to finally reach the planned total length of drainhole by drilling of an approx. 1000m long 6 ½" horizontal hole section, under-reaming it, and running and cementing a 5 ½" 45.7 ppf production liner.

Another example demonstrating the value of liner drilling technology added to the Valhall development is the well 2/8-F-11. This well (unlike the majority of development wells in the Valhall field) produces from the Hod formation which is located below the Tor formation. To successfully drill the drainhole inside the Hod 4 and 5 layers, the considerably lower pressured, but overlaying Tor production horizon had to be sealed off. To do so, it was essential that the 9 5/8" liner safely reached the top of the depleted Tor formation at 2669 m (8756 ft) MD. After the 9 5/8" Liner was drilled to its target depth, a 7 5/8" liner was set into Hod 3 at 2840 m (9315 ft) MD to isolate the Tor low pressure zone, followed by a 1548 m (5077 ft) horizontal 6 ½" drainhole. The 5" production liner was successfully run to TD of the drainhole. Due to the application of the 9 5/8" drilling liner in this case, these objectives were reached safely, and in full on this well.

In February 1998, another new drilling liner tool size was used for the Amoco Valhall application. The tool size (7-5/8", 39 lb/ft) required new design considerations and, initially, caused operational difficulties because of the small allowance between body outer diameter and liner drift diameter. In combination with designing the 7 5/8" system, the 7" system has been updated to a more modular system. The same inner string is now able to run within a range of different drift diameters with some minor modifications of the inner stabilization. *Table 1* shows a summary of drilling liner runs for the second described system in the Valhall field.

Conclusion

1. Drilling Liner Technology has been standardized to drill into depleted reservoirs of the Arun field in Indonesia and the Valhall Field in Norway. The learning curve to optimize the system is described by discussing case histories.
2. Further applications for use of liner drilling technology are discussed and limitations are shown.
3. Different used liner drill systems are introduced.

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Table 1 Drilling Liner Case Histories (Second System)

Date	Customer Location	Field Well	Liner Length	Liner Size	TD out m / ft	Drilling Distance	Drilling Time	Incl.	DLS / 100 ft	Remarks
June 1995	Mobil Indonesia	Arun C-I-16	493 m 1616 ft	7” 35 ppf	3264 m 10707 ft	24 m 80 ft	9 hrs.	56°	7°	First application, successfully entered reservoir, sidetrack section milled, no hanger used, liner set in compression, problems with releasing tool, 50 rpm
Sep. 1995	Mobil Indonesia	Arun C-II-8B	912 m 2992 ft	7” 35 ppf	3236 m 10615 ft	25 m 81 ft	16 hrs.	53°	8°	Hole under-reamed to 13 ½”, Liner hanger used, 50 rpm, still releasing tool problems, insufficient motor power.
Dec. 1995	Mobil Indonesia	Arun C-I-12	1024 m 3360 ft	7” 35 ppf	3462 m 11355 ft	60 m 198 ft	33 hrs.	51°	8°	Still releasing tool problems and insufficient motor power, 50-rpm, longest section drilled.
Oct. 1997	Mobil Indonesia	Arun C-II-6	915 m 3000 ft	7” 35 ppf	3062 m 10042 ft	12.8 m 42 ft	9 hrs.	38°	2°	System revived new motor section (XL) and new liner hanger (SDD) introduced MEPTEC & BOT involved. Former problems solved.
Nov. 1997	Amoco Norway	Valhall 2/8-F17	2080 m 6822 ft	9 5/8” 53,4 ppf	3570 m 11709 ft	19 m 62 ft	1.5 hrs.	67°	2°	First time 9 5/8” system used, longest liner length, drilled only in sliding mode due to torque limitations, Halliburton FO cementing valves used.
Dec. 1997	Mobil Indonesia	Arun C-IV-9	808 m 2650 ft	7” 35 ppf	3265 m 10708 ft	0,8 m 2,6 ft	2 hrs.	43°	2°	Drilling procedures standardized, very short drilling distance, but liner successful set.
Jan. 1998	Amoco Norway	Valhall 2/8-F11	1445 m 4674 ft	9 5/8” 53,4 ppf	2669 m 8756 ft	17 m 56 ft	3 hrs.	63°	N/A	Drilled only in sliding mode, Halliburton FO cementing valves used.
Jan. 1998	Mobil Indonesia	Arun C-II-3B	806 m 2642 ft	7” 35 ppf	3027 m 9927 ft	5.8 m 19 ft	16 hrs.	36°	3°	Differential sticking problems, mud weight decreased to solve the problem.
Feb. 1998	Amoco Norway	Valhall 2/8-A-19A	1600 m 5277 ft	7 5/8” 39 ppf	4302 m 14110 ft	7 m 23 ft	3 hrs.	60°	1,5°	First time 7 5/8” system used. Drilled only in sliding mode. Design was changed to increase overpull.
March 1998	Mobil Indonesia	Arun C-I-8	837 m 2747 ft	7” 35 ppf	3202 m 10503 ft	10,4 m 34 ft	N/A	39°	N/A	Got stuck on first trial, fished and hole under-reamed. Drilled to TD on subsequent run.
May 1998	Amoco Norway	Valhall 2/8-F14	1352 m 4434 ft	9 5/8” 53,4 ppf	2575 m 8445 ft	12 m 39 ft	2 hrs.	3°	2.5°	The hole was drilled without mud returns.
Oct. 1998	Mobil Indonesia	Arun C-II-21	655 m 2148 ft	7” 35 ppf	3556 m 11664 ft	27,4 m 90 ft	37,8 hrs.	63°	2,9°	First time DL was run across whipstock in Indonesia. No problems.
Nov. 1998	Mobil Indonesia	Arun C-IV-4ST	758 m 2487 ft	7” 35 ppf	3325 m 10905 ft	29 m 95 ft	6 hrs.	38°	N/A	Whipstock sidetrack. Collar free liner connections used (IG4S instead of TC4S). 100 rpm, longest setting depth into the Arun reservoir (61-ft).
March 1999	BPA Norway	Valhall 2/8-F10	1492 m 4893 ft	9 5/8” 53,4 ppf	2842 m 9321 ft	9 m 29 ft	2 hrs.	52°	3°	Drilled only in sliding mode.
May 1999	BPA Norway	Valhall 2/8-F-16	2451 m 8040 ft	9 5/8” 53,4 ppf	4196 m 13765 ft	1.5 m 5 ft	1.5 hrs.	56°	3°	Drilled only in sliding mode. Drilling liner stuck after drilling only 1.5 meters. Liner did not reach the objective formation and a 7-5/8” contingency liner had to be set.

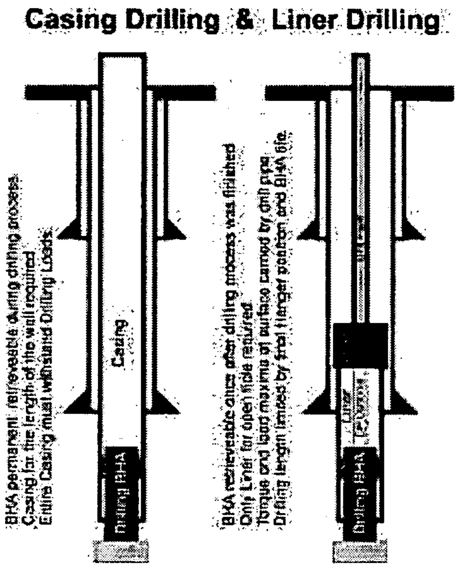

Casing Drilling & Liner Drilling
BHA permanent, retrievable during drilling process
Casing for the length of the well required
Entire Casing must withstand Drilling Loads
Casing
Drilling BHA
BHA retrievable once after drilling process was finished
Only Liner for open hole required
Torque and load maxima of surface carried by drill pipe
Drilling length limited by final hanger position and BHA life.
Liner
Drilling BHA

Figure 1:
Casing versus Liner Drilling

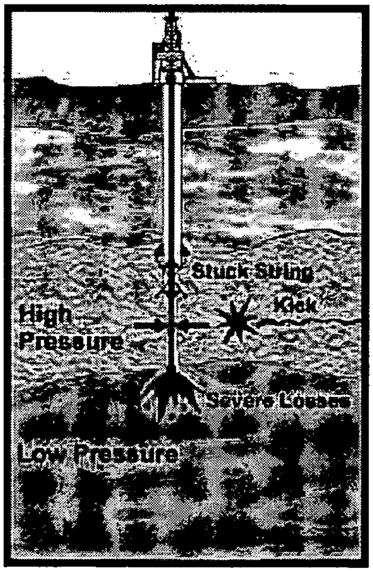


Figure2:
Drilling Depleted Reservoirs

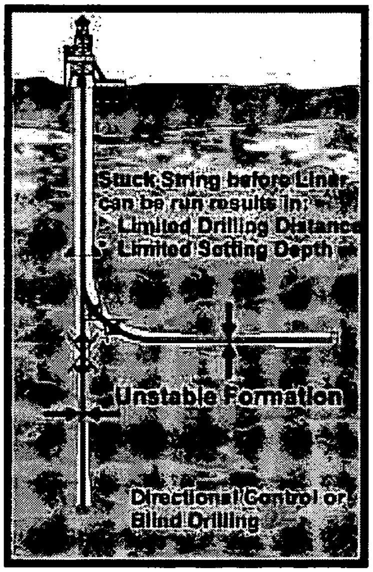

Stuck String before Liner can be run results in:
Limited Drilling Distance
Limited Setting Depth
Unstable Formation
Directional Control or Blind Drilling

Figure 3:
Extend Hole Sections / unstable Formations

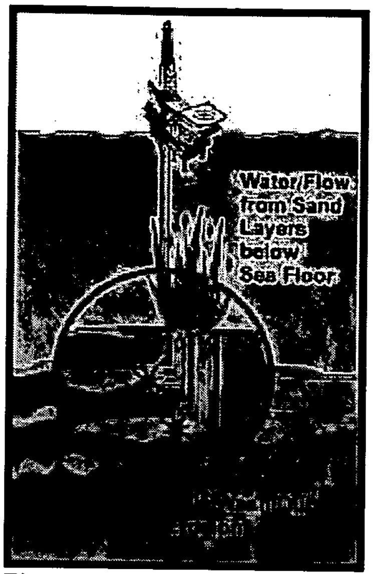

Water Flow from Sand Layers below Sea Floor

Figure 4:
Deep Water Shallow Water Flows

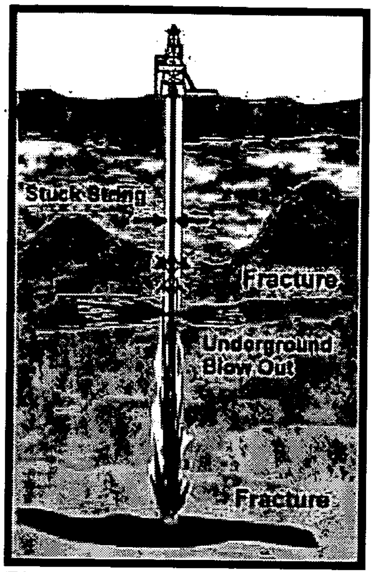


Figure 5:
Fracture at unknown Depth

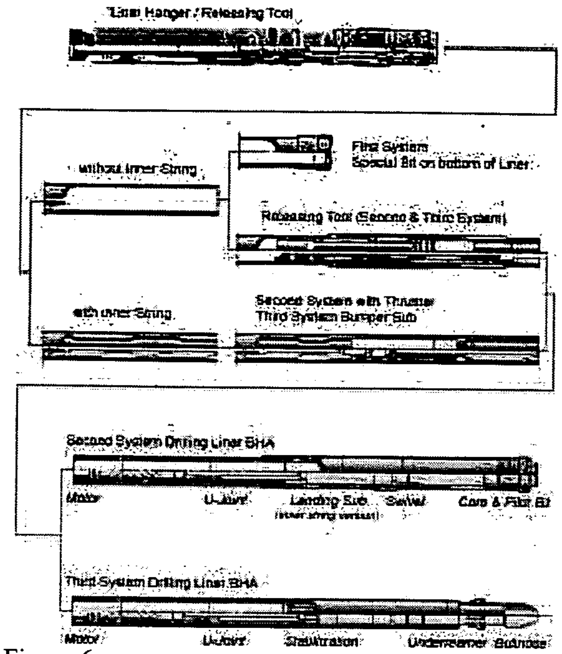

Liner Hanger / Releasing Tool
without Inner String
First System
Special Bit on bottom of Liner
Releasing Tool (Second & Third System)
with Inner String
Second System with Thruster
Third System Bumper Sub
Second System Drilling Liner BHA
Motor
U-Joint
Landing Sub
(inner string version)
Swivel
Core & Pilot Bit
Third System Drilling Liner BHA
Motor
U-Joint
Stabilization
Underreamer
Bullnose

Figure 6:
Drilling Liner Tool Matrix

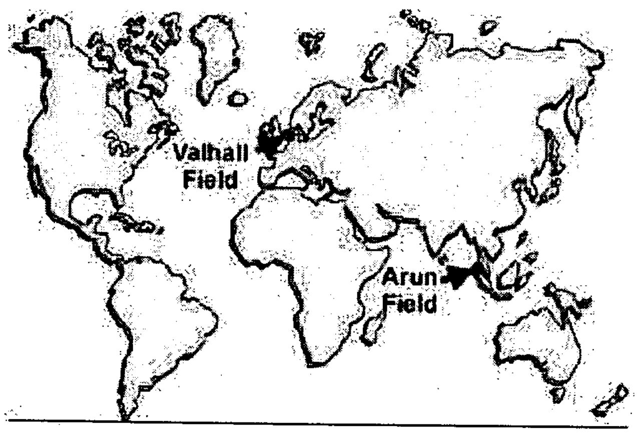
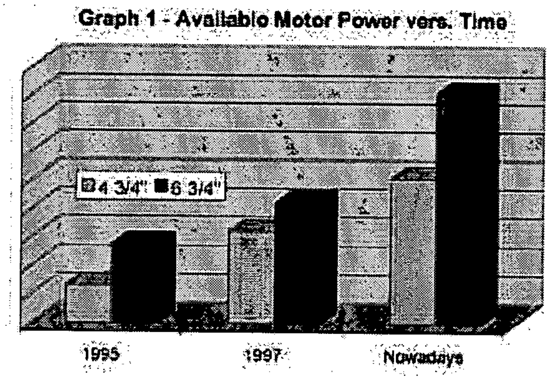


Figure 9: Location of Arun and Valhall Field.



Graph 1: Increase in available Motor Power.

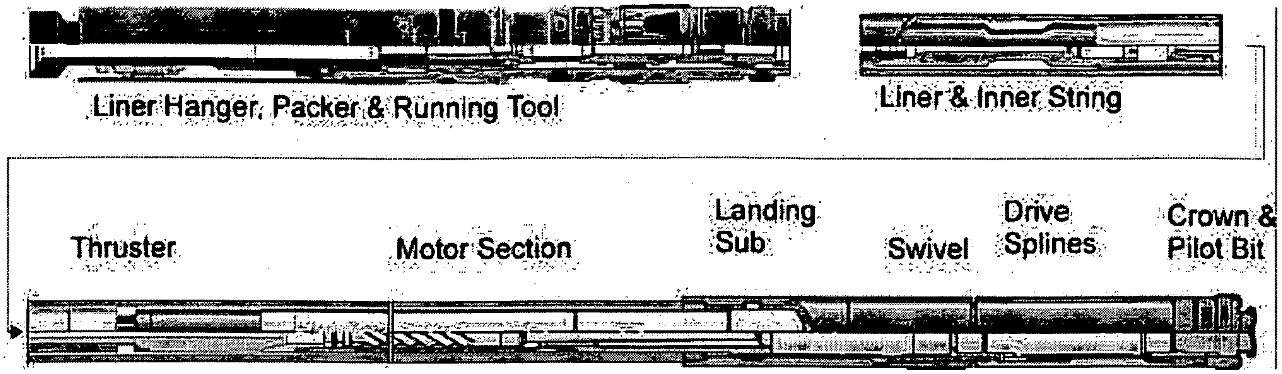


Figure 7: Used Drilling Liner String (Second System).

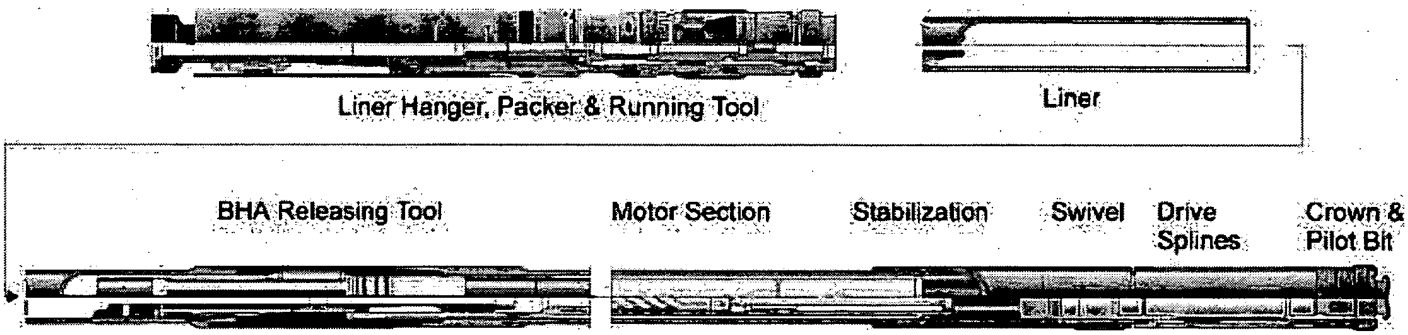


Figure 8: Proposed Drilling Liner String (Second System, Patent Pending).

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